

A LIMNOLOGICAL STUDY OF THE PLANKTON OF A
CONCRETION-FORMING MARL LAKE

M. R. RAYMOND

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY, IN THE
UNIVERSITY OF MICHIGAN

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INTRODUCTION

There is an impression among limnologists that lakes containing large quantities of marl are low in plankton production. An inspection of the literature has failed to discover any data of consequence concerning the kinds and numbers of plankton organisms present in a lake in which a large portion of the bottom is paved with marl concretions or composed of extensive marl deposits. Since such a lake, Bass Lake near Ann Arbor, Michigan, was available, a limnological investigation of it was undertaken with the following major objectives: (1) a qualitative and quantitative survey of the plankton with special reference to the net plankton (to some extent the nanno-plankton) and its seasonal, horizontal, and vertical distribution; and (2) a study of certain physical, chemical, and biological features of the environment and their effects upon the plankters.

In this paper, it is considered necessary that most or all of the bottom of a lake be covered with a substantial calcareous deposit if it is to be classified as a *marl lake*.

The writer wishes to express his indebtedness to Professor Paul S. Welch under whose direction this work was done; to Professor Frank E. Eggleton for many helpful suggestions and for aid in obtaining hydrographical data; to Professor Wm. Randolph Taylor for assistance in the identification of certain Algae; to Professor J. H. Ehlers for the identification of aquatic flowering plants; to Dr. Donald E. Miller for help in obtaining morphometric data; and to the Pleasant Lakes Club, located at Bass Lake, for permission to use certain properties and equipment. Also, the assistance of many associates is gratefully acknowledged.

METHODS AND EQUIPMENT

The shore line of the lake was surveyed by the use of the traverse method. A surveyor's transit constituted the major item of equipment. One hundred and twelve positions located at significant points along the shore at bank level were used. Three hundred and twenty-nine soundings, located by the triangulation method using two transits, were distributed over the lake as evenly as practicable. From data so secured a hydrographic map was prepared (fig. 1) from which all morphometric features were determined. Areas were measured by a polar planimeter; shore and contour lines

* Contribution from the Department of Zoology, University of Michigan.

by a standard map measurer. Temperatures were measured with a Negretti and Zambra reversing thermometer; electrical conductivity by a Dionic Water Tester manufactured by Evershed and Vignoles, London, England; relative transparency by a Secchi's disk; turbidity by the platinum wire method; and color by the United States Geological Survey glass disks.



FIG. 1

Water samples for chemical analyses were collected with a modified Kemmerer sampler. The analytical methods used for dissolved oxygen, free carbon dioxide, and alkalinity are those described in Standard Methods for the Examination of Water and Sewage (1933). Hydrogen-ion concentration was measured by means of a colorimeter manufactured by the La Motte Chemical Products Co., Baltimore, Maryland. Qualitative and quan-

titative plankton samples were obtained by straining water through a no. 25 silk bolting-cloth plankton net. All sub-surface net-plankton samples used in the quantitative work were collected by means of a modified Kemmerer sampler. Plankton concentrates were preserved immediately by the addition of 5 cc. of full-strength formalin. From time to time, a liter of the water that had been strained through the plankton net was run through a Foerst centrifuge operating at 18,000–20,000 r.p.m. The resulting concentrate was diluted to 15 cc. and preserved with formalin.

Preliminary studies of plankton counting methods showed that the most consistent and accurate results were obtained when all the organisms in two 1 cc. samples of a concentrate were counted. Consequently, this method was used.

HYDROGRAPHY

Bass Lake is a lake of glacial origin located about 1 mile southwest of Lakeland, Livingston County, Michigan. The surface elevation is 855 feet above sea level. Its position and relation to other lakes in the Huron River drainage system may be seen by referring to the United States Geological Survey, State of Michigan, Dexter Quadrangle, Geologic Folio 155.

MORPHOMETRIC MEASUREMENTS

Maximum length.....	1,152 meters
Maximum width.....	924 meters
Maximum depth.....	22 meters
Mean depth*.....	2.09 meters
Direction of main axis.....	north-south
Area.....	675,407 square meters
Total shore length (including island).....	4,843 meters
Shore development*.....	1.66
Volume*.....	1,492,466 cubic meters
Volume development*.....	0.285

* Computed by the use of formulae given by Birge and Juday (1914).

TABLE I
Areas and Volumes of Water at Various Levels

Depth Meters	Areas		Stratum Meters	Volume	
	Sq. meters	% of surface		Cubic meters	% of total
0	675,407	100.0	0–1	536,635	35.95
1	408,947	60.5	1–5	375,971	25.19
5	343,933	50.9	5–10	293,304	19.65
10	245,439	36.3	10–15	191,685	12.84
15	142,561	21.1	15–20	94,869	6.36
20	54,169	8.0			

The only inflowing stream is a small one entering on the northwest side. The greatest source of water seems to be seepage from bordering extensive swampy areas on the north and east. The location of such a swampy area is shown on the hydrographic map (fig. 1) on the north-northwest side by a break in the shore line.

Bass Lake has a small outlet on the south-east side which is inactive during part of the year. Occasionally, after a long rainy period water may also leave the lake and enter a broad swampy area located on the eastern side. This area is drained by a small, intermittent stream that enters Zukey Lake. The beginning of this old outlet into the north-east swamp area is shown on the map (fig. 1) by a broken line.

SHORE AND BOTTOM DEPOSITS

The writer has accepted the terminology and criteria of benthic habitat zones as outlined by Welch (1935). In Bass Lake, the littoral zone extends from the shore line to a depth of about 5 meters; the sublittoral, 5-10 meters; and the profundal, 10 meters to the maximum depth.

The entire littoral zone, which underlays approximately 50 per cent of the surface area, is covered with marl, most of which is in the form of finely divided particles. There is little organic material present. Extensive areas of the bottom (Welch, 1935, p. 178, 179) are almost completely covered with marl concretions. These concretions vary considerably in size, the largest ones being 5 to 6 inches or more in diameter. Several dredgings taken from scattered positions in the sublittoral and profundal zones showed that these regions, too, are covered with finely divided particles of marl, although more organic material is present than in the littoral zone. The presence of marl in the profundal region is to be expected since wave action brings it in from the shallow regions.

Most of the marl is formed through the action of Algae. A casual microscopical examination of the concretions showed a blue-green Alga, *Schizothrix fasciculata* (Nägeli) Gomont, to be very abundant. This same species was found by Pollock (1919) in marl concretions in Ore Lake about 3 miles northeast of Bass Lake. Since a thorough examination of the concretions was not made, it is possible that other Algae may occur. In addition to the formation of concretions, Algae are probably active in the formation of marl incrustations found on the surface of submerged rocks and other fixed objects, and on the posterior ends of fresh-water mussels. The extensive beds of *Chara* constitute another source of marl in Bass Lake.

PHYSICAL ANALYSES

Since a study of all temperature data revealed only the usual thermal conditions, a summary of the readings will be sufficient here (Table II). It will be noted that the temperature of the bottom water varies but slightly

from 4° C., and that there are two circulation periods, one in spring and one in autumn. Consequently, Bass Lake is a temperate lake of the second order.

TABLE II

Summary of Thermal Conditions in Bass Lake at Station 3. Temperatures Expressed in Degrees Centigrade; Thickness of Epilimnion and Hypolimnion and Limits of Thermocline in Meters

Temperature			Epilimnion		Thermocline			Hypolimnion	
Date	Surface	Bottom	Thick- ness	Fall in temp.	Limits	Temperature		Thick- ness	Fall in temp.
						Upper limit	Lower limit		
1932					no stratification				
Nov. 3	8.0	8.5			no stratification				
1933					no stratification				
Mar. 29	2.2	2.5			no stratification				
Apr. 8	4.5	4.4			no stratification				
Apr. 29	9.6	6.8			no stratification				
May 27	22.2	7.2	3	0.0	3-8	22.2	11.1	12	3.3
June 30	27.8	8.5	4	0.8	4-9	27.0	13.0	11	4.0
July 14	28.8	8.5	4	2.8	4-8	26.0	13.5	12	4.3
July 28	27.5	8.5	3	0.5	3-9	27.0	12.5	11	3.3
Aug. 11	26.2	8.5	4	0.2	4-9	26.0	13.2	11	3.0
Sept. 27	19.8	7.7	4	0.2	4-13	19.6	10.2	7	2.0
Oct. 18	12.6	7.5	13	0.3	13-16	11.8	8.8	3	0.7
Nov. 1	11.7	8.7			no stratification				
Nov. 15	4.2	4.0			no stratification				
1934					no stratification				
Jan. 20	2.6	4.0			no stratification				
Mar. 30	3.0	5.0			no stratification				

A complete study of conductivity was not attempted. Only enough readings (Table III) were taken to obtain a general indication of the quantity of electrolytes present. The data indicate that the conductance remains nearly constant throughout the year, and, also, that there is little difference in quantity of electrolytes in surface and bottom waters.

TABLE III
Conductivity Expressed in Reciprocal Megohms

Date	Station no.	Depth	Conductivity
1933			
Nov. 1	3	0 m.	330
1935			
May 22	1	0 m.	325
	2	0 m.	325
	3	0 m.	350
June 1	3	0 m.	325
	3	5 m.	330
	3	10 m.	335
	3	15 m.	330
	3	20 m.	335

Readings taken with a Secchi's disk varied from 4.75 meters to 5.25 meters, the average being slightly less than 5 meters. On the only occasion when the color of the water was tested the reading was 25. The turbidity was usually less than 7.

CHEMICAL ANALYSES

Table IV gives a summary of certain chemical features in Bass Lake. There appears to be an adequate supply of dissolved oxygen at all times, even in the deepest regions. The large areas of shallow water in which there

TABLE IV
Summary of Chemical Conditions in Bass Lake

Date	Station no.	Depth in meters	Oxygen cc. per l.	Free CO ₂ ppm.	M.O. alkalinity ppm.	Ph-th alkalinity ppm.	pH
May 29, 1931	3	0	5.95	0.0	172	3.0	8.3
		4	6.12	0.0	171	2.0	8.3
		7	6.18	0.0	172	2.0	8.2
		11	5.35	0.0	173	0.0	8.0
		13	4.99	1.0	182	0.0	8.0
Aug. 11, 1933	3	0	5.52	0.0	170	2.0	8.0
		5	5.25	0.0	170	2.0	8.0
		10	5.18	1.0	173	0.0	7.8
		15	4.83	2.0	178	0.0	7.6
		20	3.24	3.0	182	0.0	7.5
Nov. 15, 1933	1	0		0.0	196	3.0	7.8
	2	0		0.0	177	2.0	8.0
	3	0		0.0	177	3.0	8.0
		5		0.0	177	2.0	8.0
		10		0.0			8.0
		15		0.0	175	1.0	8.0
		20		0.0	185	1.0	8.0
Jan. 20, 1934	1	0	9.33	0.0	179	0.0	7.8
	2	0	8.61	1.0	180	0.0	7.8
	3	0	8.47	0.0	177	0.0	7.8
		5	7.47	0.0	175	0.0	7.8
		10	8.47	0.0	177	0.0	7.8
		15	7.97	1.0	182	0.0	7.7
		20	7.47	1.0	182	0.0	7.7
Mar. 30, 1934	1	0	8.98	0.0	160	0.0	7.8
	2	0	8.84	0.0	156	0.0	7.7
	3	0	8.63	0.5	166	0.0	7.7
		5	8.56	1.0	187	0.0	7.6
		10	8.49	1.0	182	0.0	7.6
		15	7.87	2.0	182	0.0	7.6
		20	8.01	2.0	184	0.0	7.6
June 1, 1935	3	0	5.41	0.0	154	2.0	8.0
		5	5.91	0.0	154	2.0	8.0
		10	5.98	1.0	160	0.0	7.8
		15	5.62	1.0	160	0.0	7.7
		20	4.27	1.0	160	0.0	7.5

is a good opportunity for the inclusion of oxygen from the air probably accounts in part for the amount of oxygen present. Also, there are no large quantities of organic material to use up oxygen in decomposition. Available information indicates that the pH variation is 8.3–7.5.

At the end of the summer stagnation period (Aug. 11, 1933) there was only 3 ppm. of free carbon dioxide at 20 meters depth (Table IV). Also, on Mar. 30, 1934, before the spring overturn and with ice still covering the lake, there was 2 ppm. of free carbon dioxide at 20 meters depth.

Alkalinity (Table IV) in Bass Lake is almost entirely due to bicarbonates which are present in comparatively large amounts. Phenolphthalein alkalinity, indicating presence of carbonates, is usually small or entirely absent. The quantities of fixed carbon dioxide are such as to practically make this lake a hard-water one ("third class") (Birge and Juday, 1911).

BIOLOGICAL FEATURES

The following higher aquatic plants occur very sparingly in this lake:

Potamogeton natans Linnaeus

Potamogeton heterophyllus Schreber

Potamogeton lucens Linnaeus

Potamogeton crispus Linnaeus

Potamogeton pectinatus Linnaeus

Eleocharis interstincta (Vahl) Roemer and Schultes

Eleocharis olivacea Torrey

Eleocharis palustris (Linnaeus) Roemer and Schultes

Scirpus subterminalis Torrey

Scirpus validus Vahl

Carex filiformis Linnaeus

Carex sp.

Pontederia cordata Linnaeus

Polygonum amphibium Linnaeus

Ceratophyllum demersum Linnaeus

Nymphaea advena Aiton

Castalia odorata (Aiton) Woodville and Wood

Radicula Nasturtium-aquaticum (Linnaeus) Britten and Rendle

Myriophyllum sp.

Utricularia vulgaris americana Gray

One of the outstanding features of this lake is the great scarcity of these higher aquatic plants. With the exception of a very small bed around the inlet, the entire littoral zone is almost barren.

In small areas there are dense beds of *Chara*, but the total amount of lake bottom covered with this plant is very limited.

A thorough study of centrifuge plankton was not attempted. The following plankters were found in centrifuge samples:

Microcystis flos-aquae (Wittrock) Kirchner
Aphanizomenon flos-aquae (Linnaeus) Ralfs
Dinobryon sp.
Melosira sp.
Cyclotella comta (Ehrenberg) Kützing
Rhizosolenia eriensis H. L. Smith
Fragilaria crotonensis Kitton
Fragilaria capucina Desmazières
Synedra sp.
Asterionella formosa Hassall
Navicula sp.
Amphiprora ornata Bailey
Cymatopleura solea (de Brébisson) W. Smith
Sphaerocystis Schroeteri Chodat
Dictyosphaerium pulchellum Wood
Peridinium Willei Huitfeldt-Kass
Ceratium hirundinella (O. F. Müller) Schrank
Diffugia sp.
Epistylis sp.
Brachionus sp.
Keratella cochlearis (Gosse)

TABLE V
Comparison of Centrifuge and Net Plankton

Date	Station no.	Depth in meters	Plankton No. per liter	
			Centrifuge	Net
Nov. 1, 1933	1	0	2295	320
	2	0	3285	417
	3	0	2550	297
	3	5	4590	322
	3	10	2535	235
	3	15	3150	202
	3	20	3705	307
Jan. 20, 1934	1	0	2835	80
	2	0	4410	395
	3	0	6780	865
	3	5	6660	805
	3	10	6405	270
	3	15	9360	490
	3	20	5175	570

The most numerous forms found in the centrifuge plankton were *Cyclotella*, *Synedra*, *Fragilaria*, *Dinobryon*, and *Melosira*. Since these collections were made only on two dates it is probable that other plankters were abundant at other seasons of the year.

From October, 1931, to June, 1935, more than 150 plankton samples were collected from various depths in the lake and at various seasons of the year. The usual procedure in obtaining the plankton was to take surface samples at stations 1, 2, and 3, (fig. 1) and, in addition, at station 3 to make collections at depths of 5, 10, 15, and 20 meters.

A discussion of the plankton species and groups follows. In addition, the seasonal and vertical distribution of some of the more important plankters is described. Plankton numbers, unless otherwise indicated, represent the average number for all depths per liter of lake water. Frequent reference should be made to Table VI, which has been compiled from tables showing the distribution of the plankton species as well as the plankton groups. The more detailed tables are on file in the Graduate School of the University of Michigan.

MYXOPHYCEAE

The Myxophyceae are relatively unimportant qualitatively and quantitatively. On one occasion only was there as many as 100 individuals and usually the average number was less than 50. During 1933 they were most abundant in the summer. Beginning with November, 1933, and continuing through the winter, they were present in very small numbers.

Chroococcus limneticus Lemmermann. Found only in qualitative samples Sept. 27, 1933, and Nov. 1, 1933, at all stations. Never abundant.

Microcystis flos-aquae (Wittrock) Kirchner. Most abundant of the Myxophyceae; always present. In 1933, it began to appear in numbers late in June; became most numerous in October and November, and after reaching its peak declined so abruptly that by December, it was almost absent. It did not reappear in any quantity during the winter months or early spring. It usually was most abundant at or near the surface, although, on November 3, 1932, when the lake was not thermally stratified (Table II), it was present at all depths.

Microcystis aeruginosa Kützing. Found only in qualitative samples; rare.

Merismopedia sp. Found only in June and July, 1933, in surface water and in small numbers.

Coelospherium Naegelianum Unger. A few specimens in one surface, quantitative sample, Nov. 3, 1932; often abundant in many lakes (Eddy, 1934; Smith, 1933) but apparently rare in Bass Lake.

Oscillatoria sp. Found only in a quantitative sample Nov. 3, 1932; rare.

Lyngbya Birgei G. M. Smith. Usually in surface water, from July to November, 1933; also found Nov. 3, 1932; quantities small.

Anabaena Lemmermanni P. Richter. Mostly in surface water, in June, August, September, October and November, 1933; usually rare.

Anabaena limnetica G. M. Smith. Two peaks of production, one in May, June, and early July, and another in November; appears earlier in summer than *A. Lemmermanni*; usually in surface stratum.

TABLE VI
Number of Individuals per Liter in Various Plankton Groups

Plankton group	Date	Sta. 1	Sta. 2	Sta. 3				
		0.0 m.	0.0 m.	0.0 m.	5 m.	10 m.	15 m.	20 m.
Myxophyceae	Nov. 3, 1932			137	90	72	82	197
Chrysophyceae				175	60	140	252	197
Bacillarieae				682	585	485	617	2647
Chlorophyceae				0	0	2	0	2
Dinophyceae				55	47	22	15	45
Protozoa				17	5	0	0	0
Rotatoria				42	40	47	72	182
Cladocera				2	12	5	10	10
Copepoda				40	22	40	45	107
Total				1150	861	813	1093	3387
Myxophyceae	Nov. 12, 1932	55	65	82		52		
Chrysophyceae		147	102	145		140		
Bacillarieae		817	735	800		637		
Dinophyceae		2	15	5		10		
Rotatoria		47	45	52		40		
Cladocera		2	7	10		2		
Copepoda		15	40	32		35		
Total		1085	1009	1126		916		
Myxophyceae	Mar. 29, 1933	7	15	10	7	5	5	
Chrysophyceae		22	117	37	37	35	65	
Bacillarieae		2997	14700	3637	4310	3485	3295	
Chlorophyceae		0	0	2	0	0	0	
Dinophyceae		0	0	2	2	2	0	
Rotatoria		17	45	40	52	52	52	
Cladocera		0	0	0	0	0	2	
Copepoda		5	32	17	22	37	22	
Tardigrada		0	5	0	0	0	2	
Total		3048	14914	3745	4430	3616	3443	
Myxophyceae	Apr. 8, 1933	5	2	5	0	2	2	0
Chrysophyceae		25	27	37	15	35	42	30
Bacillarieae		4635	4210	3820	2817	3050	3275	2802
Dinophyceae		0	0	0	5	0	2	0
Rotatoria		20	45	27	32	32	45	57
Cladocera		0	0	0	0	0	2	0
Copepoda		0	20	17	27	25	32	37
Total		4685	4304	3906	2884	3144	3400	2926
Myxophyceae	Apr. 29, 1933	7	0	5	5	0	0	0
Chrysophyceae		2	7	0	22	5	5	0
Bacillarieae		1792	1342	907	1405	1327	1292	890
Dinophyceae		25	20	27	37	5	2	0
Rotatoria		65	77	97	72	127	70	60
Cladocera		0	0	0	2	0	2	0
Copepoda		45	60	70	57	40	30	12
Total		1936	1506	1106	1600	1504	1401	960
Myxophyceae	May 27, 1933	15	35	45	10	0	0	0
Chrysophyceae		16540	22665	5805	6170	1042	330	335
Bacillarieae		547	612	547	1082	2215	757	762
Chlorophyceae		0	2	0	0	0	0	0
Dinophyceae		350	567	607	182	30	45	32
Rotatoria		160	285	215	122	92	145	192
Cladocera		0	5	0	2	5	7	10
Copepoda		102	72	72	45	80	97	110
Total		17714	24243	7291	7613	3464	1381	1441
Myxophyceae	June 30, 1933	20	52	92	27	42	7	2
Chrysophyceae		30	85	67	127	47	10	10
Bacillarieae		107	150	185	262	195	92	87
Dinophyceae		442	555	1120	4247	332	145	120
Protozoa		0	0	0	45	2	0	5
Rotatoria		35	10	37	20	10	7	50
Cladocera		0	0	5	15	10	0	7
Copepoda		20	27	22	62	25	65	80
Total		654	879	1528	4805	663	326	361

TABLE VI (Continued)

Plankton group	Date	Sta. 1	Sta. 2	Sta. 3				
		0.0 m.	0.0 m.	0.0 m.	5 m.	10 m.	15 m.	20 m.
Myxophyceae	July 14, 1933	10	37	92	17	7	0	2
Chrysophyceae		65	22	37	175	5	27	5
Bacillariaceae		355	327	327	460	30	125	57
Dinophyceae		170	227	70	825	62	127	105
Protozoa		5	0	0	5	0	0	0
Rotatoria		5	27	12	17	5	17	50
Cladocera		5	0	2	2	2	2	5
Copepoda		10	10	7	27	32	72	75
Total		625	650	547	1528	143	370	299
Myxophyceae	July 28, 1933	45	27	92	10	2	2	5
Chrysophyceae		297	420	422	230	10	12	12
Bacillariaceae		102	165	142	182	82	57	60
Dinophyceae		142	110	120	682	37	37	65
Protozoa		2	2	0	5	2	0	0
Rotatoria		17	25	105	62	10	7	100
Cladocera		0	0	0	15	5	2	0
Copepoda		10	17	15	90	52	67	67
Total		615	766	896	1276	200	184	309
Myxophyceae	Aug. 11, 1933	72	57	75	60	5	10	2
Chrysophyceae		87	67	195	165	0	5	7
Bacillariaceae		35	35	67	25	30	75	52
Dinophyceae		102	132	85	85	12	22	37
Protozoa		0	2	5	0	0	0	2
Rotatoria		47	42	55	285	7	5	42
Cladocera		0	0	0	2	2	2	2
Copepoda		72	37	35	32	62	37	42
Total		415	372	517	654	118	156	186
Myxophyceae	Sept. 27, 1933	10	65	22	32	15	2	7
Chrysophyceae		332	635	720	420	17	12	25
Bacillariaceae		142	345	525	447	115	47	25
Dinophyceae		242	392	355	440	27	25	77
Rotatoria		72	75	80	70	15	22	5
Cladocera		0	0	0	10	2	5	0
Copepoda		27	25	22	85	25	82	5
Total		825	1537	1724	1504	216	195	144
Myxophyceae	Oct. 18, 1933	45	52	52	55	57	22	7
Chrysophyceae		830	1015	1030	945	555	70	42
Bacillariaceae		167	260	310	252	237	95	60
Dinophyceae		125	132	147	90	47	45	130
Protozoa		0	0	0	0	2	0	5
Rotatoria		110	82	107	112	90	57	7
Cladocera		5	2	2	5	5	10	0
Copepoda		10	20	10	22	27	355	17
Total		1292	1563	1658	1481	1020	654	268
Myxophyceae	Nov. 1, 1933	30	125	10	20	15	10	12
Chrysophyceae		30	67	35	60	10	7	25
Bacillariaceae		77	120	107	155	137	110	147
Dinophyceae		35	35	20	15	10	12	10
Rotatoria		137	55	110	42	35	32	55
Cladocera		5	5	5	2	0	5	10
Copepoda		5	10	10	27	27	25	47
Total		319	417	297	321	234	201	306
Myxophyceae	Nov. 15, 1933	2	15	40	12	5	27	5
Chrysophyceae		2	20	12	12	5	10	5
Bacillariaceae		130	155	357	195	162	162	220
Dinophyceae		5	7	2	0	7	7	17
Protozoa		0	0	0	0	0	0	5
Rotatoria		62	45	40	35	32	27	27
Cladocera		0	0	15	2	12	7	7
Copepoda		15	12	20	17	32	35	20
Total		216	254	486	273	255	275	306

TABLE VI (Continued)

Plankton group	Date	Sta. 1	Sta. 2	Sta. 3				
		0.0 m.	0.0 m.	0.0 m.	5 m.	10 m.	15 m.	20 m.
Myxophyceae	Jan. 20, 1934	2	0	12	5	10	5	2
Chrysophyceae		2	5	0	0	0	0	0
Bacillariaceae		67	372	817	765	202	452	522
Dinophyceae		2	7	7	0	5	0	5
Rotatoria		5	5	15	15	40	15	27
Cladocera		0	0	0	2	0	2	0
Copepoda		0	5	15	17	12	15	12
Total		78	394	866	804	269	489	568
Myxophyceae	Mar. 30, 1934	2	5	2	0	5	0	0
Chrysophyceae		4200	2060	2255	35	5	7	25
Bacillariaceae		65	27	87	792	1795	1675	675
Dinophyceae		25	30	22	42	0	2	5
Protozoa		0	2	0	0	0	0	0
Rotatoria		55	12	7	102	40	27	15
Cladocera		2	0	0	0	0	0	0
Copepoda		15	7	20	55	20	10	7
Total		4364	2143	2393	1026	1865	1721	727

m.—meters.

Aphanizomenon flos-aquae (Linnaeus) Ralfs. Never abundant but generally distributed; not found in May, June, or July, 1933; most abundant at or near the surface.

CHRYSOPHYCEAE

The Chrysophyceae were at times the most numerous net-plankton group. The seasonal distribution was very irregular. The largest number was found on May 27, 1933, when there were 7,555 per liter, while a month earlier there was only an average of 6 per liter. Some of this great difference in number may be attributed to certain natural agencies, because the colonial plankter, *Dinobryon*, was the most abundant of the Chrysophyceae and since an individual or a large or small colony was counted as one, it is conceivable that certain factors such as severe wave action might break up large colonies and result in an apparent increase in the number of organisms. However, not all of the differences are due to such influences, but most are due to an actual increase in the number of colonies.

Mallomonas sp. Found only in qualitative samples in small numbers.

Chrysosphaerella longispina Lauterborn. Reached its maximum abundance in 1933 in October, when there were 609 colonies per liter. It first began to appear late in June; reached a minor peak of production in July (54 per liter); was less numerous in August; and in early September began to increase until the maximum was reached. On Oct. 18, 1933, it was by far the most abundant plankter. During the periods of greatest abundance, most of the colonies were found between the surface and 10 meters depth. At other times, the colonies were almost evenly distributed throughout all depths. Data tend to show that at times there is an uneven horizontal distribution within the lake, these differences often being more than 100 colonies per liter.

Synura uvella Ehrenberg. This species was found in March, 1933, and in March, 1934, in small numbers. On both occasions, it was collected only in surface water.

Dinobryon divergens Imhof.

Dinobryon bavaricum Imhof.

Dinobryon stipitatum Stein.

Dinobryon sociale Ehrenberg. Due to the similarity of the various species of *Dinobryon*, no attempt was made to count them separately, but they were counted as a group. Consequently, this discussion must necessarily cover the four species. However, an examination of the qualitative samples seemed to indicate that all of the species reached their maximum abundance at about the same time. It was also observed that when the group was the most abundant *D. sociale* outnumbered the other species. Some one species was present in significant numbers in every one of the quantitative samples. During 1933, the group reached its maximum abundance in May, when there were as many as 22,000 colonies per liter in the surface water. On this date, a very large part of the plankton was made up of *Dinobryon*. During the period of greatest production, most of the colonies were found in the upper stratum. Available data indicate that there may be great differences in the horizontal distribution of this group.

BACILLARIEAE

While the Bacillarieae were at times exceeded in number by other groups, it was, on an average, the most abundant group of plankton in Bass Lake. Only during the warm summer months (June, July and August) was this group present in small numbers. Unlike some other plankton groups it did not show sudden increases or decreases in number. Except for the period of about three months in the summer, the number remained fairly constant. Also, unlike most other groups, the large numbers were due to two or three predominant plankters, namely: *Fragilaria*, *Synedra*, and *Asterionella*. In addition, there were other diatoms present which, when compared to *Fragilaria* and *Synedra*, might be considered scarce, but when compared to many other genera, would be regarded as relatively abundant. *Melosira* sp. This species, present in most of the quantitative samples, had two peaks of production in 1933, one in April and one in November. On Nov. 3, 1932, the average number per liter was 60, which was the maximum number found. Although it never was as abundant as some of the other Bacillarieae, it must be considered an important organism in the plankton. At times, this plankter was quite evenly distributed throughout the strata of the lake at station 3; at other times, there were greater numbers in the lower strata; on still other occasions it was most abundant at or near the surface. At all times, the surface distribution was fairly uniform.

Cyclotella comta (Ehrenberg) Kützing. Found in the quantitative collections on only two occasions and in small numbers.

Rhizosolenia eriensis H. L. Smith. This diatom is transparent and extremely hard to detect in plankton collections. Consequently, it is difficult to draw any conclusions regarding its abundance or distribution in the lake. In 1932, data indicate that it was most numerous on Apr. 29, when the average number of individuals per liter was 35.

Tabellaria fenestrata (Lyngbye) Kützing. Found in collections from March to July, 1933, and reached its maximum abundance (16 per liter) in 1933 in April. This species never became as abundant as some of the other diatoms.

Fragilaria crotonensis Kitton. This was one of the most numerous of all the plankton organisms. It was found in every collection in considerable quantities. In 1933, it reached its maximum abundance in March and April. At that time, there were more than 2,000 colonies per liter. Although this species was never as abundant at any one time as *Dinobryon*, its average abundance over a long period of time was higher. Occasionally, this form had a very uneven horizontal distribution, as for example, on Mar. 29, 1933, there were approximately 5,000 more colonies per liter at station 2 than at station 1. Also, the vertical distribution varied considerably with different seasons; at times, the colonies were very evenly distributed, while at other times they were more numerous either at the top or at the bottom.

Fragilaria capucina Desmazières. Most abundant in 1933, on Apr. 8, when there were 62 colonies per liter. By June, 1933, this form had entirely disappeared from the plankton and did not reappear until November. This species was usually most abundant near the surface. In the surface water the number per unit of volume varied considerably.

Synedra pulchella (Ralfs) Kützing.

Synedra Chaseana B. W. Thomas. In counting, no attempt was made to separate the different species of *Synedra*. It is possible that there may have been present one or more species other than the two mentioned above. This genus had its peak of production in 1933 in March. It was at times the most abundant plankter. On March 29, 1933, at station 2, there were 7,000 individuals per liter. This form at times shows a very uneven distribution, both horizontally and vertically. Of the two species listed above, *S. Chaseana* was always the more numerous.

Asterionella formosa Hassall. Present in all collections except those taken in August, September, and October, 1933. It was most numerous May 27, 1933, (582 colonies per liter) but within two months it had entirely disappeared. It reappeared in November, 1933, and steadily increased in numbers until March, 1934, when the last collection was made. Usually, it would be difficult to understand how an organism could

steadily increase in numbers at a time when, in most lakes, the physical and chemical factors are becoming more and more unfavorable. However, in Bass Lake, it is possible for this to happen since the environmental factors remain tolerable for this species throughout the winter. As in the case of the other diatoms, *A. formosa* at times had a very uneven horizontal and vertical distribution.

Navicula spp. Various species of *Navicula* occurred in small numbers in several collections.

Pinnularia sp. Found only in qualitative samples and in very small numbers.

Gyrosigma sp. Found in one quantitative sample collected Apr. 29, 1933.

Amphiprora ornata Bailey. A species appearing sporadically in small numbers.

Cymbella aspera Ehrenberg. A form appearing in small numbers only in the qualitative samples.

Cymbella sp. A form never found in the quantitative samples. It is possible that it may be a new species. In some respects it is similar to both *Cymbella tumida* Grunow and *Cymbella ventricosa* Kützinger but it differs from the first in having too few striae and from the latter in lacking the rostrate ends. Its length is 37–40 microns; its width, 10–11 microns; and it has 7–8 striae in a space of 10 microns.

Cymatopleura solea (de Brébisson) W. Smith. Although this species appeared in several of the quantitative collections, it was not abundant enough to be an important plankton. The largest number found was on Nov. 15, 1933, when there was 1 per liter. Its occurrence was sporadic.

Cymatopleura elliptica (de Brébisson) W. Smith. A form never found in the quantitative samples.

CHLOROPHYCEAE

There were no predominant plankton organisms that belong to the Chlorophyceae; all Chlorophyceae occurred in relatively small numbers. There was almost a complete absence of desmids, a group that often makes up a large percentage of the plankton in some lakes.

Eudorina elegans Ehrenberg. A species found in one qualitative sample, Apr. 29, 1933.

Sphaerocystis Schroeteri Chodat. Very rare.

Pediastrum Boryanum (Turpin) Meneghini. Found in one quantitative sample on May 27, 1933. Also found in small numbers in a few qualitative samples.

Westella botryoides (W. West) de Wildeman. Found in only one qualitative collection.

Dictyosphaerium pulchellum Wood. Found in quantitative samples only on Nov. 3, 1932, and Mar. 29, 1933.

Spirogyra sp. Rare.

Closterium sp. Never abundant.

Cosmarium sp. Found only in qualitative collections.

Staurastrum sp. It is possible that there may be more than one species of *Staurastrum* in Bass Lake. Found only in qualitative collections.

DINOPHYCEAE

With respect to numbers, the Dinophyceae were the third most abundant group in Bass Lake, ranking behind the Bacillarieae and Chrysophyceae. The abundance of this group was due almost entirely to *Ceratium hirundinella* which was present in maximum numbers during June, July, August and September, but during the remainder of the year nearly disappeared from the plankton. The group reached its maximum abundance during 1933, on June 30, when there was an average of 994 individuals per liter present, all of these being *Ceratium hirundinella*.

Peridinium Willei Huitfeldt-Kass. This species was never very abundant, 15 individuals per liter being the largest number found. The data are not complete enough to draw definite conclusions concerning its seasonal distribution. It was decreasing in numbers when the first collections were made in the spring, 1933, and was increasing in abundance when the last collection was made in March, 1934, but possibly had not yet reached its peak of production. At the time when the maximum number was found, this species was most abundant at a depth of 5 meters, but absent at 10 meters and below.

Ceratium hirundinella (O. F. Müller) Schrank. A plankter having two peaks of production in 1933, a major one in June and a minor one in September. In June, 1933, this was the most abundant organism in the plankton, averaging about 1,000 individuals per liter. At the time of its greatest abundance, this species was found to be most numerous at a depth of 5 meters; at other times it was usually present in larger quantities at or near the surface. On many occasions, this organism showed an uneven horizontal distribution.

PROTOZOA

None of the organisms classified as Protozoa ever became numerous. *Diffugia* sp. During 1933, this plankter was found in the samples collected from June to November. It was never abundant, the highest average being 7 individuals per liter on June 30, 1933.

Actinosphaerium eichorni Ehrenberg. Found in small numbers in qualitative samples only.

Vorticella sp. Usually found attached to *F. crotonensis*. During the period of this investigation it was found in only one quantitative collection in small numbers.

Epistylis sp. Found only in one quantitative collection and in very small numbers.

ROTATORIA

The Rotatoria were the most numerous zooplankters. Specimens representing five genera composed most of the rotifer fauna. They reached their maximum abundance in May, 1933, when there was an average of 173 individuals per liter. The minimum number was present in July, while in September and October there was again a slight increase in the number.

Brachionus sp. In 1933, this species had two peaks of production, one in May when there was an average of 85 individuals per liter, and another in August when there was an average of 51 individuals per liter. On most occasions, this plankter had an uneven horizontal and vertical distribution.

Conochilus unicornis Rousselet. Found in small numbers in some qualitative samples.

Filinia longiseta (Ehrenberg). Present in one or more of the quantitative collections on every date on which samples were taken except those of November, 1933, and of January, 1934. It was most abundant on Apr. 29, 1933, when there was an average of 20 individuals per liter.

Keratella cochlearis (Gosse). A species whose peak of production was in late fall in both 1932 and 1933. It was relatively abundant throughout the summer of 1933, and was present in the smallest quantities in March and April of the same year. This plankter was often more abundant in the lower regions of the lake than in the upper strata. Usually it was rather evenly distributed horizontally, but occasionally a striking lack of uniformity was noted.

Keratella quadrata (O. F. Müller). Appearance sporadic; rare.

Lecane luna (O. F. Müller). Found only in one of the quantitative samples, Nov. 12, 1932.

Monostyla lunaris (Ehrenberg). Known only from one collection, Mar. 29, 1933.

Notholca longispina (Kellicott). In 1933, it was most abundant in May when there was an average of 57 individuals per liter. There was a sharp decline in the numbers immediately after the maximum abundance was reached. In the scale of abundance of rotifers it occupied third place.

Polyarthra trigla Ehrenberg. In 1933, this plankter was most numerous in October and November. On Oct. 18, there was an average of 28 individuals per liter. At other seasons of that year, it was present in relatively small numbers. Absent only from those collections taken Apr. 8, 1933, and Jan. 20, 1934. This plankter was usually most abundant in the upper stratum of the lake (from the surface down to a depth of 10 meters). It often showed considerable variation in its horizontal distribution.

Synchaeta tremula (O. F. Müller). Found in small numbers in certain qualitative collections.

Testudinella patina (Hermann). One specimen found in one qualitative sample.

Testudinella sp. Never abundant.

CLADOCERA

The largest average number found was 6 individuals per liter.

Daphnia retrocurva Forbes. During 1933, this species was present in the summer and fall. It made its appearance about the first of May and became most numerous on June 30, when there was an average of 5 individuals per liter. After June 30, the number was smaller.

Bosmina longispina Leydig. This species was most abundant (5 individuals per liter) in November of the years 1933 and 1934. During the summer months of 1933, it was either present in small quantities or apparently absent.

COPEPODA

The largest number of Copepoda found was 82 individuals per liter on May 27, 1933. The seasonal distribution shows that there were two peaks of production in 1933, one in May and another in October.

Diaptomus oregonensis Lilljeborg. During 1933, this species was most numerous in May, when there was an average of 8 individuals per liter. At other times, this plankter was always present, although in small numbers.

Cyclops leuckarti Claus. This species was the most abundant of the copepods. It was found in one or more samples on every date on which collections were taken. This species became most abundant late in the fall in both 1932 and 1933. On Nov. 3, 1932, there was an average of 25 individuals per liter, and on Oct. 18, 1933, there was an average of 42 individuals per liter. This organism varied in numbers at other times of the year, the smallest numbers being present during mid-summer, 1933.

Cyclops sp. Found in small numbers in qualitative samples only.

TARDIGRADA

Macrobiotus sp. Found in a few qualitative samples only.

POLYZOA

Fredericella sultana Blumenbach. The presence of this species in Bass Lake was reported by Brown (1933). The writer has repeatedly seen this organism attached to various aquatic plants. In October, 1935, it was very abundant, growing on almost every submerged plant stem. Only

the statoblasts were found in the plankton and they were never abundant.

TABLE VII

Showing the numbers of genera and species within the taxonomic groups represented in the net plankton of Bass Lake

Group	Number of species	Number of genera
Phytoplankton		
Myxophyceae	10	8
Chrysophyceae	7	4
Bacillariaeae	17	13
Chlorophyceae	10	10
Dinophyceae	2	2
Zooplankton		
Protozoa	4	4
Rotatoria	12	10
Cladocera	2	2
Copepoda	3	2
Tardigrada	1	1
Polyzoa	1	1
Total	69	57

TOTAL NET PLANKTON

The net plankton reached its maximum quantity late in May after the vernal overturn when the average number of plankters per liter was slightly more than 9,000. The summer minimum was found in August when there were about 300 individuals per liter. After the autumnal overturn there was another pulse. This occurred in October when there was an average of about 1,100 organisms per liter. By Nov. 1, the plankton production had dropped to 300 per liter, remaining at about this level throughout the winter. The data concerning the seasonal distribution of the total net plankton agree, in a general way, with those obtained by Birge and Juday (1922). However, during March, 1934, with ice still covering Bass Lake, and at a time when unfavorable conditions are usually present in most other lakes, there was a marked increase in the amount of plankton. It has already been pointed out (Table IV; also pp. 8 and 10) that there was neither a deficiency in dissolved oxygen nor an accumulation of free carbon dioxide at a time of the year when such conditions are usually expected. Consequently, the reasons for this plankton pulse in Bass Lake must rest upon conditions not known at the present time.

Although the curve representing the seasonal distribution of plankton in Bass Lake is of the usual bimodal form, it is evident that the total quantity of plankton is small when compared with that of many other lakes. Certain other comparable lakes are known to produce a quantity of plankton much greater than was found in Bass Lake. Some lakes considered to be moderately high in plankton productivity contain at times of maxi-

imum production as many as 100,000 or more individuals per liter. The minimum production in some lakes is never as low as the highest number found in Bass Lake. It is clear that Bass Lake, which in 1933, was found to range in average number from a minimum of about 300 to a maximum of about 9,000 individuals per liter, has a scanty plankton crop.

A survey of the list of species given in this report shows that Bass Lake does not have a unique plankton. The species found to be most numerous in Bass Lake are also found in many other lakes, and are often the most abundant forms in these other lakes. However, the predominant species in Bass Lake do not reach the maximum numbers that sometimes occur in certain other bodies of water.

It has already been pointed out that the plankton of Bass Lake is restricted quantitatively and, since many species known to occur in other lakes were not found in Bass Lake, it is apparent that its plankton is also qualitatively restricted.

It seems probable that the plankton of Bass Lake is a *selection biota*, i.e., a group composed of those organisms, out of a larger and much more widely distributed population, which can withstand the conditions found in a marl lake.

Although detailed studies have not been made with regard to other organisms in the lake, observations have clearly shown that bottom fauna and fish populations are very scanty. As a consequence, any reduction of the plankton crop by plankton feeders is minimal.

DISCUSSION

Thus far in this report, data have been given concerning (1) certain physical and chemical factors; (2) the results of the plankton survey; and (3) additional biological features of Bass Lake. In this section of the paper, the investigated environmental factors will be considered in order to determine, if possible, which ones are responsible for the low plankton production. Some factors will be designated as favorable, and are thus regarded as influences not responsible for the low plankton production. Certain other factors, unfavorable in general to plankton production, exist and operate in Bass Lake, but there they are no more effective than in other lakes of the same region. Therefore, they too may be disregarded as contributing agents in the particular complex here being considered. Since environmental factors do not operate independently, they must be discussed in relation to one another.

The form of a lake basin has considerable influence on productivity. Approximately 40 per cent of the surface of this lake is underlaid by water having a depth of 1 meter or less, and about 50 per cent of its surface has water beneath it that is 5 meters or less in depth. It is now a well-established limnological principle that the productivity of a shallow lake is usually

higher than that of a comparable, deep lake. Needham and Lloyd (1930, p. 73) state that "The shallower a lake is the better its waters are exposed to light and air, and, other things being equal, the richer its production of organic life." Welch (1935) sets forth this principle as follows: "Within limits and under strictly comparable conditions, the greater the areas of shallow water the greater the biological productivity." If the form of the basin alone is considered, Bass Lake should be highly productive. However, conclusions cannot be drawn concerning the productivity of a body of water from a study of a single factor, such as depth. Probably large areas of shallow water are ordinarily necessary for a high production of life in most lakes. However, this investigation shows that the presence of these large areas does not necessarily insure high productivity.

Shore development should be considered among the productivity factors. It is generally agreed that the greater the shore development, other things being equal, the richer the production of aquatic life. The shore development of Bass Lake is 1.66. This is considered medium, and, therefore, should not be a factor singularly limiting the quantity of plankton.

It seems quite unlikely that temperature has any greater influence on the plankton of Bass Lake than it has on that of other lakes in the same general region. Since the temperature records reveal the usual thermal conditions, this factor can be ruled out as having no special reducing effect upon the plankton.

Welch (1935) states that "It has been claimed that, other things being equal, the richer a body of water in electrolytes the greater the productivity." In Bass Lake, there are quantities of electrolytes (325–350 reciprocal megohms) (Table III) larger than any found in the 530 lakes and lakelets investigated by Juday and Birge (1933) in which the range of conductance was from 6 to 124 reciprocal megohms. Some of these lakes are spoken of by Juday and Birge as having "fair" or "moderate" amounts of electrolytes, even though they are in a region in which it is known that most of the lakes belong to the soft or medium hard-water classes, and, therefore, do not contain as many electrolytes as those lakes located in a region rich in lime. According to Welch (1935) the maximum known conductivity reading in Michigan lakes is 330 reciprocal megohms. It seems evident, then, that Bass Lake has, at least, a moderately high conductivity. Although the rôle of electrolytes in natural waters is not as yet fully understood, this quantity would seem potentially adequate for rather high productivity. The method used here for measuring electrolytes was not qualitative, and no statement can therefore be made concerning their nature. It is possible that in Bass Lake there may be a deficiency of certain needed or even required electrolytes. It is not known whether in such a supply certain ones may be present in quantities above the optimal limits.

The transparency of Bass Lake was not so low as to abnormally hinder

the photosynthetic processes of the phytoplankton, since green plankters were found thriving at all depths. Of the 470 lakes investigated by Juday and Birge (1933), for example, about 400 had a lower transparency than Bass Lake. In comparison with lakes in general, Bass Lake could probably be said to be moderately transparent. Many lakes with lower transparency produce larger quantities of plankton, and so transparency can be ruled out as having any special limiting influence on the plankton. The two factors, color and turbidity, which are closely associated with transparency, do not have any special significance since they are well within the range found in productive lakes.

Table IV shows that there is an abundance of dissolved oxygen in the lake at all times and at all levels. In the hypolimnion it did not decline below 3.24 cc. per liter during the summer of 1933. Even in the deepest regions of the lake there was enough to potentially maintain the plankton. Also, in winter, when the oxygen in the deepest stratum of many lakes is nearly or even completely depleted, there was an ample supply. It seems evident, then, that the dissolved oxygen content is never so small that it has any reducing effect on the production of plankton in Bass Lake.

Hydrogen-ion concentration is probably not a factor that affects the number of individual plankters representing the species now present in Bass Lake any more than it affects the number of individuals of the same species in other lakes with a similar pH range. Certain other lakes having a pH range similar to that in Bass Lake are known to produce a larger quantity of plankton. It is possible, however, that pH may play some part in determining what species are present in a lake. It is well known that lakes having a high hydrogen-ion concentration (low pH value) usually support an abundant growth of desmids, and lakes having a low hydrogen-ion concentration, such as Bass Lake, usually have more diatoms. Whether or not the limiting factor here is pH is not clear since pH is often closely related with certain other factors which may affect productivity.

The nearly complete, and at times complete, absence of free carbon dioxide is probably a factor which limits the numbers of plankters in Bass Lake, at least, to a certain extent. Due to the absence of free carbon dioxide at certain times of the year, organisms that carry on photosynthesis must obtain this product from bicarbonates which are present at all times. Just how many organisms can do this is as yet unknown. It seems quite probable that the plants in Bass Lake that carry on photosynthesis must necessarily make use of the half-bound carbon dioxide of the bicarbonates, since it is practically the only source of this necessary product. Höll (1932) claims that certain species of *Peridinium* are not found in some waters because of a scarcity or complete absence of free carbon dioxide. However, he also points out that *Peridinium Willei* (the only species of *Peridinium* found in Bass Lake) is able to thrive when but small amounts of free carbon

dioxide are present. Since some species appear to be ruled out of certain waters by a scarcity or absence of free carbon dioxide it seems quite likely that others may be similarly eliminated.

In Bass Lake there are large quantities of bicarbonates formed from the union of carbon dioxide and monocarbonates. Table IV shows that whenever carbonates were present in the water there was a complete absence of detectable free carbon dioxide, a condition which is to be expected. These large amounts of bicarbonates should be conducive to a rather high plankton population since hard-water lakes are, in general, more productive than soft-water lakes.

The writer believes that the presence of large amounts of marl (largely calcium carbonate) in the littoral zone of Bass Lake is indirectly responsible, to a large degree, for the low plankton production. Pond (1905) showed that the substratum of a lake furnishes some nourishment for rooted aquatic plants, and that it does not serve merely as a place in which plants may be anchored. Furthermore, he showed that the kinds of soil in which rooted aquatic plants reached their maximum growth are, for the most part, similar to those in which land plants grow best. This means that a soil or substratum containing considerable quantities of nutritive substances is necessary for a luxuriant growth of rooted aquatic vegetation. That marl produced in connection with Algae contains very little organic substance was pointed out by Pollock (1919). Although the marl in Bass Lake was not analyzed chemically, an inspection of it showed that it was a nearly homogeneous mass, containing small quantities of organic material, which probably are not sufficient for an optimum growth of rooted aquatic vegetation.

The author believes that one of the factors responsible to a large degree for the low plankton production of Bass Lake is the scarcity of rooted vegetation. The idea that such vegetation is indispensable as a contributor of many essential nutritive substances is by no means a new one. Some of the early investigators observed the scarcity of such vegetation in certain lakes and also the low productivity but did not correlate the two facts. Thompson (1896) reported that "The flora of Pine Lake [Michigan] is exceedingly meager. The observer may row along its shores for miles without seeing one thrifty bed of water weeds, and may dredge back and forth over a hundred acres of bottom without securing a handful of vegetation." In the same report, Thompson claims that "The tow net and dredge, therefore, collect but little of such material [filamentous algae] but the Diatomaceae are ever present." Pine Lake is one that may be classified as a marl lake, but from a description of the bottom given by Thompson, it is evident that the amount of marl present is not nearly so great as in Bass Lake. Although Thompson gives a list of the species of Diatomaceae observed in Pine Lake, his data are meager and can not be compared with those for

Bass Lake. Thompson found that the Diatomaceae "greatly outnumbered all other plants both as to species and individuals," which is exactly what was found in Bass Lake.

Kofoed's statement (1903) that "Other things being equal, bodies of fresh water free from vegetation (submerged macro-flora) produce more plankton than those rich in such vegetation" seems to be in contradiction to what has been found in this investigation. However, Kofoed was dealing mainly with *Ceratophyllum* which, according to Pond (1905), is not a true rooted plant, and, therefore, does not absorb salts from the substratum, but is more completely a competitor of the plankton for many nutritive substances than are the true rooted plants.

Klugh (1926) summarized the literature dealing with the relation that exists between higher aquatic vegetation and productivity in an attempt to see if the presence of such vegetation can be used as an index of the productivity of a lake. He concluded that "It would appear that the amount of rooted submerged vegetation *may* be such an index character." This study on Bass Lake seems to add more evidence in support of the theory reviewed by Klugh. He also summarized the various points in connection with the part which the higher aquatic plants play in the productivity of lakes. Since the absence of these plants appears to be such an important factor in the lake under investigation it is in order to repeat some of the major points. They are: (1) rooted aquatic plants are able to absorb certain salts from the soil, and when they decay these salts go into solution in the water where they become available to other aquatic organisms; (2) these plants, on decomposition, add certain essential organic substances which, according to many investigators, aid in the growth of planktonic algae; (3) these plants, on decay, contribute particulate matter which may be used as food by some organisms; (4) they serve as places of attachment for both algae and for various life history stages of many animals; and (5) they directly provide food for many organisms.

Although chemical analyses were not directly made to determine the exact amount of calcium present in the water in Bass Lake, there can be no doubt that there are large amounts there since (1) the area around the lake has lime deposits brought down originally by the glacier and water draining into the lake carries this lime with it; (2) the bottom of the lake is covered with marl; (3) the methyl orange alkalinity is high indicating the presence of calcium; and (4) the amount of free carbon dioxide is low indicating a chemical combination with calcium. Certain small amounts of calcium are necessary as an essential constituent of the protoplasm of most aquatic organisms, and it has been shown that, under normal conditions, the more calcium in water, other things being equal, the greater the productivity. However, this investigation tends to show that under the conditions existing in Bass Lake calcium, in combination with other ele-

ments, may be so abundant that it becomes indirectly detrimental. These large amounts of calcium affect the productivity of a lake in a number of ways, the most important of which are: (1) calcium carbonate unites with free carbon dioxide to form calcium bicarbonate thereby robbing the lake of a substance (free carbon dioxide) which is a factor controlling, to some extent, the productivity; (2) free carbon dioxide, amounts of which are dependent upon the amounts of monocarbonates present, determines to some degree the pH, which in turn influences somewhat the nature of the plankton; (3) the deposition of calcium carbonate forms a type of bottom unsuitable for rooted aquatic plant growth, and the scarcity of plants results in an absence of a turnover of essential nutritive materials. The author believes that these unique combinations of factors and influences which in a sense are, to some extent, all dependent upon the amounts of calcium, form an environment which restricts plankton production.

SUMMARY

1. This paper represents the first detailed limnological investigation of a typical marl lake. Special attention was given to the plankton. Not only does this lake possess a bottom completely covered with a deposit of marl but also it is especially unique in its production of immense quantities of marl concretions.

2. The first hydrographic map of this lake is presented and served as the basis for all morphometric considerations contained in this paper.

3. Temperature, electrolytes, transparency, color, turbidity, dissolved oxygen, hydrogen-ion concentration, free carbon dioxide, carbonates and bicarbonates were studied with special reference to their possible influence on plankton production.

4. This lake offered the unusual opportunity to study plankton production in a body of water practically devoid of higher aquatic plants.

5. The principal features of the plankton are as follows:

(a) The net plankton contained a total of 69 species representing 57 genera. It thus appears that the plankton is qualitatively very restricted.

(b) In the nanno-plankton, 21 species were identified, about half of which belonged in the Bacillarieae.

(c) The nanno-plankton exceeded the net plankton in quantity.

(d) The Bacillarieae were, on the average, the most abundant of all the plankton groups, both as to the number of species and as to the number of individuals.

(e) Qualitatively, Bass Lake does not have a unique plankton. Most of the species occur in other types of lakes. The plankton is probably a *selection biota*.

(f) Quantitatively, the plankton is very restricted when compared to that of other lakes.

6. Temperature, conductivity, transparency, color, turbidity, dissolved oxygen, and hydrogen-ion concentration, as they exist and operate in Bass Lake, are factors believed not to be responsible for the low plankton productivity. Those factors whose combined effects form conditions unfavorable for plankton productivity are: the large amounts of marl, the scarcity of free carbon dioxide, and the paucity of rooted aquatic vegetation.

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